Design for Manufacturability

George T. Halmos

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By George T. Halmos

There are millions of product designs made around the world every year but only a part of them are considered a success. A new product can be truly evaluated and the designer recognized only after the designed object is built. A building or a bolt, a structure or a machine, a rocket or a manure spreader has very little value - regardless of how ingeniously it has been designed - if it remains on paper and it is never built.

The ideal combination exists when a well designed product is manufactured at the right price, has the right quality and can be easily marketed. There is a long list of cleverly designed products which failed because they could not be manufactured or transported at the required price or they were difficult to erect or assemble and could not be marketed. These products are considered to be poorly designed, regardless of how excellent the idea behind them is, and fail, not as a result of inadequate structural strength or appearance but, as a result of the cost of material, labour or capital investment.

The fact that plant personnel - with a respectful exception of a few - are unable to design an economical, good structure, building or bridge is evident to civil engineers, structural designers and architects. However, it is taken for granted that civil engineers, structural designers, architects or mechanical engineers can design products which can be efficiently manufactured. This assumption is disputed by many manufacturing personnel. The truth is that expertise and knowledge are required for both design and manufacturing.

Quite frequently the balance between success and failure has nothing to do with the calculation or structural strength, approach or basic idea. It often depends only on how the drawings are dimensioned, how tolerances are specified, where the holes, notches and bending lines are located or what material thickness or width has been specified.

The objective of this paper is:

1) to point to neglected areas which should be considered for manufacturability,
2) to highlight some of the common pitfalls,
3) to indicate where a minor or major change can make the difference between economical or uneconomical manufacturing, and
4) to emphasize the importance of communication between product designers, tool designers and manufacturing personnel.

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Most of the products to be discussed in this paper are considered to be manufactured in sheet metal or structural shops repeatedly and in large quantities. However, the conclusions can be applied to single jobs and individual products as well.

FORMING

This presentation will not cover the basic rules of roll forming but will highlight a few, frequently overlooked points.

1. Bending Radii

The minimum bending radii for different combinations of material thicknesses and qualities are available in numerous tables. The corner radii of the inner forming rolls usually are made to match the specified minimum radii.

Rolls designed for a specific profile must usually serve for more than one thickness of material. The roll design is based on the thickest material, to provide adequate space between top and bottom rolls. The mill operator compensates for the thickness difference by adjusting the top shaft up or down, thus the varying gap between top and bottom rolls (see Figure 1).

Gaps between the rolls which are not horizontal can also be changed by placing or removing shims between the split rolls. However, this procedure takes a considerable amount of time and, therefore, in most cases it is either not practiced or it is restricted to minimum usage.

For siding, roofing and structural components it is preferred to leave the shims unchanged or, if dimensions are critical, they may be changed in the final two - three passes. Shimming in the last passes may also be required for spring-back adjustment when materials with a wide spread in their physical characteristics are formed.

Proper dimensioning of the profile drawings is a great help to the tool designer. The dimensioning and tolerances should take into consideration the forming method, need for thickness compensation by adjusting upper shafts and/or axial shimming. Figure 2 gives the recommended method for dimensioning a flute or cell and Figure 2b shows why the thinnest material will have practically the same inside radius as the thickest one. For designing light gauge sheet metal products the bending radius required for the thickest material shall be specified for all thicknesses. A typical example is shown below for material where the minimum inside bending radius is restricted to two times the thickness of material.

Max. Panel Thickness .075" (1.9 mm) $R = .15"$ (3.8 mm) or $R = 2\ t$
Min. Panel Thickness .020" (0.5 mm) $R = .15"$ (3.8 mm) or $R = 7.5\ t$

This data can be critical when strength, web crippling or other characteristics are calculated. When forming high strength - low elongation material, such as ASTM A466 Grade E, or unannealed, the minimum bending radius should be larger. Following the above example the .020" (0.5 mm) thick Grade E material will have a bending radius of 15t or .30" (7.5 mm).

The tool designer should be informed of the physical characteristics of all possible materials to be formed. It is more important to know the anticipated actual maximum yield and other characteristics than the specified minimum in the standards. The formability of the material is related to its physical properties and influences the number of passes required for proper forming.

Unannealed steel with approx. 80,000 psi (550 MPa) and 2% - 4% elongation (ASTM A446 Grade E) usually cannot be formed with tooling designed for material with maximum 45,000 psi (310 MPa) yield and 20% elongation. If rolled, the material may exit the mill slit at each bending line. On the other hand, all lower yield, higher elongation materials can be formed with rolls designed for high strength material.

At first glance this restriction could call for all rolls to be designed for high strength material. However, this would require, in most cases, larger bending radii and more stands resulting in higher tooling costs.

Roll form designers prefer to work with reasonably tight radii which helps to "set" or stabilize the profile. Forming very large radii, as shown in Figure 3, takes only one or very few passes but it does not "set" the material. It results in limited permanent deformation, and, therefore, it is difficult to keep the shape and dimensions.

2. <u>Width of Non-Formed Sections</u>

Too wide or too narrow unformed elements between the first bend line and the edge of the strip, or unformed sections between two bend lines can create problems. Figure 4 shows the simplified path of the strip edge while roll formed to 90°. During the forming operation the original "L" long edge must stretch by "e" to keep continuity. Once the edge is in the 90° position, it will run parallel to the bend line. To have the same length as the bend line the stretched edge must contract back to its original length. There will be no visible effect if the elongation which occurred during the forming process is within the elastic limit. However, if the "H" is too high and/or the "L" is too short the edge may be permanently elongated. In this latter case the edge will remain longer than the bend line resulting in a "wavy" edge (see Figure 6). The wavy edge can be eliminated or the waviness can be minimized by keeping the leg short, or by introducing an additional bend line close to the strip edge, as shown in Figure 7, and/or utilizing more passes for forming. The additional bend line can also help in the case of coils shipped with a wavy edge by the mills.

A distance between the edge and the nearest bending line that is too short may create forming problems (see Figure 5). For easy formability the length of the "leg" is preferred to be six times the material thickness (6t) or at least 4t.

The width of the "leg" may become too narrow or too wide during the rolling because of a variation in set-up, "wandering" or moving of the coil, or change in strip width.

A panel with six cells or flutes will have 12 segments that are almost vertical. A .010" (0.24 mm) change in the height due to tightness or looseness of upper shafts could result in an approx. .120" (3 mm) change in blank or strip width. This change will influence the width of the "leg".

The coils are usually guided in the roll forming mill by edge guides. Changing the location of the coils or telescoping coils, the position of the guide or camber in the coil will move the centre line of the coil to the left or right thus making one edge wider and the other one narrower.

Slit edge coils usually have a tight width tolerance ($\pm$ .005" or .15 mm) but mill edge coils may have a wide range of tolerances. Most wider coils are purchased with a mill edge because slitting represents a substantial extra cost. The fluctuation in blank size or change in the relative location of the edges may create other problems. Some examples are shown in Figure 8. A long leg may create problems in the forming process, deformed lock seam or difficulties with erection. A short edge distance can cause other problems or a lack of strength.

The leg length can be tightly controlled with a special, but more expensive, roll design shown on the right hand side of Figure 9. This process requires tight width tolerance and offers less flexibility.

The ratio between the depth and width of the cell as a function of material thickness should always be considered when the profile is designed. Relatively thin, unsupported rolls may break frequently when forming narrow and deep flutes (see Figures 10a and 10d). Forming thicker and/or higher strength materials results in higher pressure and increases the probability of roll breakage.

Production of narrow but shallow grooves or offsets as shown in Figure 10b does not usually create problems. When the stiffener rib is close to the edge of the roll the slenderness of the roll should be taken into consideration (Figures 10c and 10d).

Leaving a relatively wide strip between two bend lines does not usually present any problem in roll forming but the appearance of the finished panel can be poor. A large percentage of the commercially available coiled products are not completely flat but have either a wavy edge or a wavy centre, the latter one described as "full centre" or "oil canny appearance". These imperfections are induced during the rolling process at the mill and cannot be removed by straighteners or levellers. Roll forming may minimize the effect by distributing the ripples but there is a good chance that the "oil canny" effect will show up in webs wider than 6" when light gauge material is roll formed. Glossy surface and paint will accentuate this unsightly effect which is shown on the left side of the panel drawn in Figure 11. The right hand side of the same panel shows a typical groove stretched into the material to break the surface into smaller segments and disipate the waviness. Embossing or the occasionally used cross-ribbing also eleviates the effect of the "oil canniness".

3. Limitations of Section Height

The distance between the top and bottom shafts is called the vertical centre distance. Most roll forming lines have a limitation on the distance the top shaft can be lifted.

In the case of spur gears or "fixed position" design the top shaft may not be lifted at all.

If the upper shaft is driven with long addendum gears, depending on the design, the top shaft may be lifted up to 1/8" or 3/16".

A linkage system in the gears, depending on the make, type and size of the roll forming head, will allow lifting the upper shafts by approx. 3" - 6".

The largest vertical adjustment is feasible with forming mill stands driven by a separate gear box and shafts with universal joints, or shafts driven by individual motors or when the top shafts are not driven at all.

To explain the significance of the vertical distance let's take an example illustrated in Figure 12.

Example:	Max. Vertical Distance	V=8"	(203.0 mm)
	Shaft Diameter	d=3"	(76.2 mm)
	Spacer Thickness	Ts=.25"	(6.3 mm)
	Width of Profile	W=3"	(76.2 mm)
	Width of Leg	L=1"	(25.4 mm)
Question:	Is it possible to fit the 3" wide "C" channel into the roll former?		
Calculation:	Top Shaft Half Diameter	1.25"	(32.0 mm)
	Thickness of Spacer	.25"	(6.3 mm)
	Space Between Profile and Spacer (to allow bending of up leg)	.162"	(4.1 mm)
	Profile (out to out max.)	3.0"	(76.2 mm)
	Bottom Roll Minimum Thickness	1.0"	(25.4 mm)
	Bottom Shaft Half Diameter	1.25"	(32.0 mm)
	TOTAL (vertical distance required)	6.912"	(176 mm)

Answer: The vertical distance will not prevent the forming of the specified "C" channel in the mill. However, to form a "Z" section with the same width and length would require a mill with a maximum vertical shaft distance of approx. 9.33" (237 mm) (calculation not shown), and will not fit in a mill with 8" max. vertical centre distance.

4. Forming Angles

Due to the nature of the roll forming method it is relatively easy to form shapes up to or close to 90^{o}. To form multiple bend lines in a panel over 90^{o} is more complicated and would require additional side stands or other methods (see Figure 13). However, bending over 90^{o} in special shapes made from narrower widths is very common. Some typical examples are shown in Figure 14.

5. Continuity of Bend Line

It is accepted by every designer that bend lines increase the strength of a flat sheet but the weakness introduced by the discontinuity of the bend line is frequently forgotten.

Figure 15 illustrates a few examples where, by design or by incorrect forming, the straight bend line is discontinued or damaged.

Figure 15a represents a panel with longitudinally rolled ribs formed into cross crimped material. The bend lines of the previous cross crimping cannot always be "ironed out" and shows up as a "bump" on the bend line. This design also introduces other problems, such as elongating the panels along the ribs which the centre part remains close to its original length.

A similar problem can occur when a panel "cross-ribbed" in prior operation is roll formed with a longitudinal bend line going over the cross-ribbing as shown in Figure 15b.

Embossing the flat material for composite deck purposes is common. If the embossing is not properly lined up with the bending lines (see Figure 15c) a similar effect to the one shown in Figure 15a can happen.

In the case of a prefabricated metal building panel for curved buildings, the original bend line was straight but the improper method of curving destroyed the continuity of the bend line resulting in reduced strength of the entire building. By improving and modifying the edge condition in the curving die the strength of the panel was improved by close to 40%.

The left part of Figure 15e illustrates a typical acoustic panel. The perforation in the web barely influences the strength of the deck. However, forming a fully perforated panel with holes at the bending line, as shown on the right hand side of the same figure, may reduce the strength by 70%! Drainageholes in the decoratively perforated stainless steel can contribute to the buckling of shelves in refrigerated supermarket displays or punched out holes at the bend line may induce a weakness in the upright of a storage rack (see Figure 15f).

6. Profiles Manufactured in Different Sizes

To meet different load or other requirements economically the designer frequently has the option to select from shapes made in different thicknesses and in a variety of sizes. The tooling cost to manufacture a profile in more than one size varies from practically nothing to the cost of a full set of tooling for each size.

The designer of the roll formed profile greatly influences the tooling and production costs by specifying the right, variable dimensions before the tool design starts. For example, different diameters of corrugated spiral pipes can be produced by simply changing the entry angle of the strip without additional tooling. A 36" (914.4 mm) wide building profile can be converted to 900 mm (35.43") metric coverage for practically no extra tooling cost if the rolls are split at the right place and an insert prepared when the roll set is made. The length of the legs of a "U" channel can be varied within a certain limit by varying the blank size when roll formed with conventionally designed rolls shown on Figure 9a.

In the case of "C" channels, which is basically a "U" channel with legs bent inwards, the above mentioned change cannot be achieved so simply because the inward facing legs are usually formed in the early passes, restricting size changes in the subsequent passes. However, multiple widths of both "U" and "C" channels can be easily manufactured within certain limitations by changing the position of rolls, as shown in Figure 16. Figure 17 illustrates this principle for both "C" and "Z" sections. Changing the "W" dimension shown in Figures 17a and 17c does not require additional rolls and frequently both types of sections are rolled with a combination set of dies. Changing the "H" dimension indicated in Figures 17b and 17d requires a complete set of tooling for each size. Extra cut off dies or cut off die insert would be required for all different sizes regardless of whether the "W" or "H" dimension is different.

The forming of a "C" channel is a symmetrical process, bending both legs upwards while the rolling of a "Z" channel is an asymmetrical process because one edge of the strip is forced up and the other one down during forming (see Figures 18a and 18b). The forcing of one leg up and the other down induces stresses into the finished "Z" section resulting in a twist of the finished product. To eliminate or minimize this "twist" and keep the edge of the strip at about the same height, the roll designers prefer to shape the "Z" section at an agles as shown in Figure 19.

The forming of the "Z" section at an angle does not lend itself for width adjustment and each size of section requires a separate set of rolls. Therefore, this method is usually used only in the case of large run quantity requirements.

Table 1 provides the price ratio of rolls, using the price of tooling for one size of "C" channel as one.

Time and space does not permit to detail other influencing factors such as the effect of pre-cutting or post-cutting, set up time, operator's skill, or to list other examples in storage racks, prefabricated buildings, etc.

Another example is the grain bin side sheets, rolled in the thickness range of .025" - .135" (0.65 mm - 3.4 mm) and curved to radii 3' - 50' (0.91 m - 15.2 m) without extra tooling cost. However, the variation in hole pattern requires serious consideration. The cost of a piercing die to punch all holes in one hit may be in the $25,000 - $30,000 range. Depending on design, one company can pierce all grain bin and feed tank sheets with one die, another needs over 15 such piercing dies.

7. Secondary Operations

Many products are used, applied or erected as rolled only, but the largest percentage of them require additional manufacturing operations. The shaping of the profile during roll forming is usually called primary operation and all others are referred to as secondary operations.

The secondary operations are:

Piercing	Curving
Notching	Marking
Lancing	Coining
Stitching	Arc Welding
Louvering	Resistance Welding
Mitreing	Adhesive Bonding
Slitting	Painting
Cutting	Caulking
Embossing	Interleafing
Bending	Etc.

All these operations may be performed separately, before or after roll forming. In practice the handling of each piece individually, at each operating station requires considerably more production time than needed for the highly productive roll forming.

Combining the above operations in the roll forming line can eliminate or minimize the manufacturing and material labour cost required for the secondary operations and eliminates extensive in-between operation storage space.

To demonstrate the influence of the manufacturing or dimensioning and tooling cost method the possibilities of manufacturing "C" channels will be discussed in detail.

The "C" channel with end holes only or with holes in-between the end holes (see Figure 19) can be manufactured in the following sequence:

pre-cut, pre-pierce, ROLL FORM
pre-cut, ROLL FORM, post-pierce
PRE-CUT, ROLL FORM, post-pierce
ROLL FORM, CUT, post-pierce
ROLL FORM, CUT, PIERCE
PIERCE, ROLL FORM, CUT
ROLL FORM, PIERCE IN THE CUT OFF DIE, CUT TO LENGTH
ROLL FORM, PIERCE AND CUT IN ONE HIT DIE

Note: Operations performed in the roll forming line are noted in capital letters.

The length tolerance on the product ("L") will depend on the accuracy of the pre-cutting operation or on the accuracy of the roll forming mill. The tolerance on the hole distance ("l") will depend on the method of piercing, gauging and the number of holes pierced in one hit.

If the endholes are pierced with punches incorporated into the cut off die then the hole distance from the edges (distances marked as "e" and "f" in Figure 19) will be very accurately held but the tolerance on the end hole to end hole distance (dimension "l") depends on the length tolerance capability of the roll forming line.

If all holes are pierced in one hit before or after forming the tolerance on hole distances can be kept with .005" (0.13 mm). The method of piercing holes between the end holes will similarly influence the tolerance. If all holes are pierced from gauging one end then the drawing should be dimensioned accordingly. If holes are pierced in the cut off die then dimensioning and tolerances will be different. This little example indicated the interaction between dimensions and tolerances, manufacturing method and the cost of manufacturing equipment capable of producing goods to the dimensions and tolerances specified on drawings.

8. Material

The designer of the profile usually specifies the physical characteristics of the material based on the combination of strength requirement, accepted trade practice and availability. The profitability and success of the product can be greatly influenced by considering or neglecting a few other material related factors.

a) Physical Characteristics

The primary suppliers of steel or other metals charge "extra" for certain specified physical properties or chemical compositions. The same minimum yield material may be purchased with or without guaranteed properties at a different price level depending on the type of ASTM or other specification.

b) Width

The lowest (base) price of the material is usually applied to a certain width range, let's say 36" - 48". Extra charges are made for anything under or over the base range. Sometimes a small increase or decrease in the width puts the same material into a different price range.

The width tolerance is also a matter of cost. The base price covers mill tolerances which are relatively loose. Slitting provides an average $\pm$.005 width tolerance (0.13 mm) but increases the price.

c) Thickness

Rules, similar to those of the width, also apply to the thickness. Different thickness groups have different extra charges for material supplied with standard mill thickness tolerance. When tighter tolerances are specified further extra charges must be paid.

d) Quantity and Inventory

The base price is charged on minimum mill order quantities which may be 40,000 lb. (18 150 kg). Smaller quantities can be purchased from the mills or steel centres, warehouses at higher prices. When designing a product with a larger variety of thicknesses, such as pre-engineered buildings, grain bins, arched buildings, etc., it is sometimes more economical to "group" small quantities of different thicknesses and use a heavier, common thickness.

In the case of building panels and many other products, it is advantageous if the designer is familiar with the inventory kept in the plant. Selecting identical blank sizes for different profiles can significantly reduce the inventory carrying charges. It costs the company about $350,000 for each $1,000,000 of inventory carried for one year!

e) Surface, Coating and Corrosion in Manufacturing and Storage

Hot rolled steel is in the lowest price range but it will rust easily. The oxide layer on the HRS is very abrasive and should be roll formed with rolls made from the right tooling material. The scale flaking of the steel can also be "messy" and it is not recommended to fabricate HRS material with machines used for prepainted or other sensitive materials.

Pickled and oiled material will eliminate most of the above mentioned problems - but, again, only for an extra cost.

Very little extra precaution is needed when fabricating galvanized material. Zinc pick-up on forming rolls can be a problem and the plant must have proper ventillation at the welding station to exhaust toxic fumes. Tightly nested galvanized sheets and profiles will develop white rust under humid storage conditions.

Some companies specify oil to prevent or retard the white rust but oil is definitely not recommended for roof sheets because of safety hazards during erection.

The minimum bending radii of prepainted material may be larger than the radii of the parent material. Too sharp radii can crack the paint and white rust will appear along the formed corners.

It is impractical or incorrect to specify certain operations, such as spot welding and stud welding to prepainted surfaces.

f) Other Material Characteristics

In addition to the yield, tensile and elongation other characteristics, such as formability, aging, weldability, heat resistance, chemical or corrosion resistance, thermal expansion and others, should occasionally be checked to avoid unpleasant surprises.

9. Labour Content of the Product

The conversion or labour cost of the goods is an important, but frequently overlooked, aspect at the time of design. This may stem from the fact that material weight, thus cost, can be easily calculated but it requires considerable experience and shop knowledge to estimate man hour per piece, linear foot or square foot.

The labour/material cost ratio of the product depends on many factors, including design, run quantity and manufacturing method. The average labour content of products used in the construction industry varies from 5% to 50%.

"C", "Z" sections, culverts	5 - 7%
Roofing, siding	9 - 12%
Grain bins	14 - 16%
Lockers, toilet partitions	40 - 50%

The above figures should be used as guidelines only and are increased or decreased by varying conditions. Some minor factors, such as "nestability" of the product, has such an impact on cost that it can influence the designer when shape is established.

Nestable panels and decks can be manufactured at full mill speed, while non-nestable profiles, when every second piece must be turned over 180° at the mill run out table, may run at 60% of full speed. If separating blocks must be placed manually between panels then the run speed may be reduced to 25%, increasing the labour cost accordingly.

Prefabricated building frames may be designed to minimum material content but fabrication labour cost, including welding, can increase the total manufacturing cost to an unacceptably high level.

As material is available at about the same price for all competitors, the saving in labour becomes more significant. The design stage is the best time to consider all manufacturing cost elements, including set up times, rolling speed, handling, weight, etc. Some minor items, such as piercing of additional holes for drainage or for hanging in the paint line and forming dimples to separate painted sections during drying, may not cost any extra but can save considerable labour in the subsequent operations.

10. Material Handling and Packaging

The shape of the product will influence the material handling, packaging and transporation costs. Length, width, weight, rigidity, nestability and surface sensitivity are only a few items to be considered. Too short pieces increase handling costs while too long pieces may create in-plant, transportation or job site material handling problems. Too wide or too high products need a special transport permit and/or cannot be transported over certain routes.

Nestable panels, decks, etc. can be shipped by weight. When non-nestable products are shipped, lots of "air" is transported. The company may be required to send two or more truckloads to the job site when, weight wise, one should be sufficient.

11. Erection and Assembly

As most of the formed products are either assembled in the factory or erected in the field, it is very important to consider all possible avenues for saving.

A small taper or radius at the end of the shape, direction of burr, or a one or two degree change in the angle can make a significant difference during assembly or erection. Sections have been designed, tooled up and fabricated just to have it realized on the job site that tools cannot reach the desired locations. Other products are too confined for welding, bundles of roof decks could not be separated in the field, barn roofing could not be nailed. Closed sections of some products collect liquid during chemical treatment in the paint line and cannot be drained. Hundreds of actual examples prove that most of the problems can be avoided and product cost reduced when the designer takes the complete process into consideration from raw material purchase to the final stage of assembly.

12. Conclusion

Practical examples cited in this presentation are intended to prove that, in addition to the strength and dimensional requirements, a designer should also consider other influencing factors, such as formability, cost and availability of material, capacity and cost of manufacturing equipment, flexibility in tooling, material handling, transportation, assembly and erection.

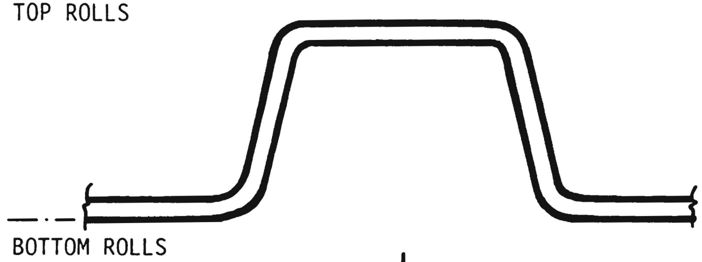
The cost of the product and its final success is often dependent upon the designer's foresight when the shape and manufacturing process is determined.

Good communication between the product designer, manufacturing personnel, tool designer, material handler, erector, salesman and/or customer is critical and important to achieve the best combination of product function and price.

TABLE 1

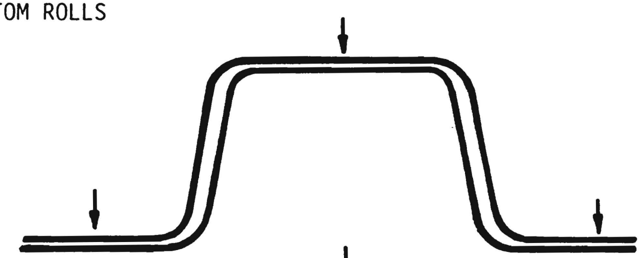
Relative Cost of Roll Sets for Different Size and Shape Combinations
(approximate guide only)

		"C" Section			"Z" Section			Total No. of Sections	Cost
a	Single Set of Rolls		10"					1	1.0
b	Single Set of Rolls					10"		1	1.05
c	Adjustable Rolls	8"	10"	12"				3	1.10
d	Adjustable Rolls				8"	10"	12"	3	1.20
e	Combination Set	8"	10"	12"	8"	10"	12"	6	1.35
f	Rolls Forming at Angle					10"		1	1.0
g	Rolls Forming at Angle				8"	10"	12"	3	3.0



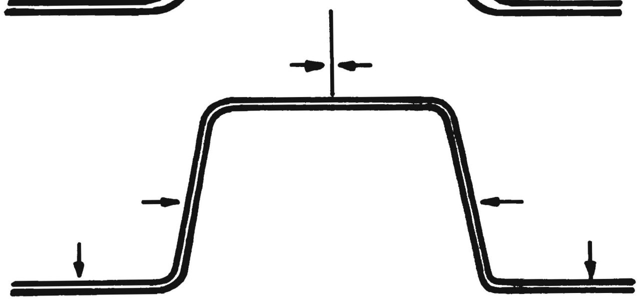
Gap Between Rolls is Designed for the Thickest Material to be Rolled

FIGURE 1a



Top Rolls are Moved Down for Thin Material
(This Action Takes Little Time)

FIGURE 1b



Top Rolls are Moved Down and Shifted Sideways by Changing Shimms
(Adjustment Takes Considerable Amount of Time)

FIGURE 1c

Adjusting Top Rolls to Suit Various Material Thicknesses

FIGURE 1

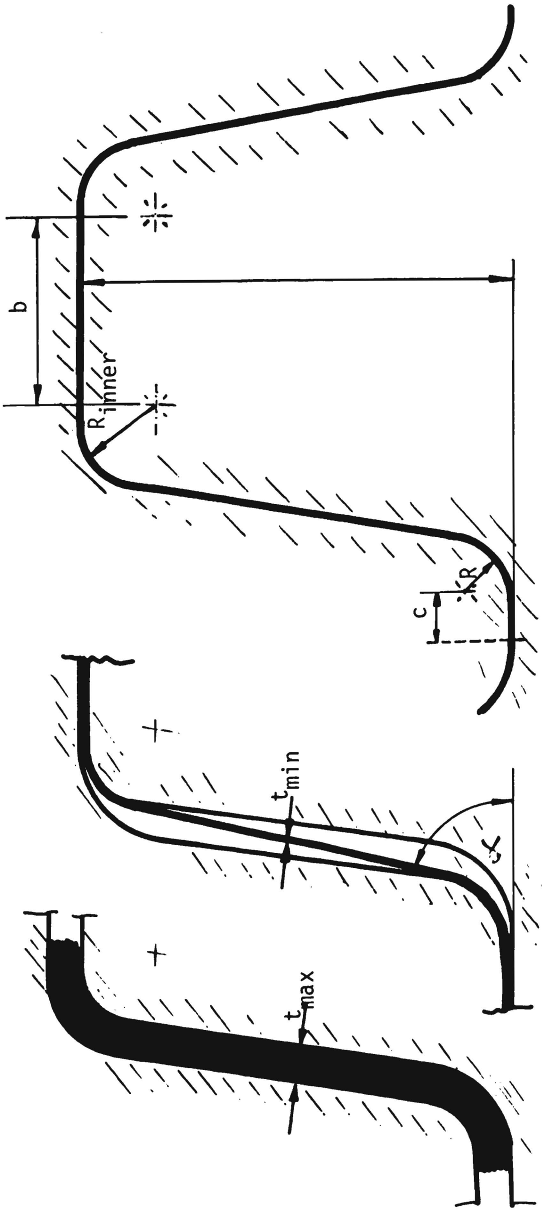
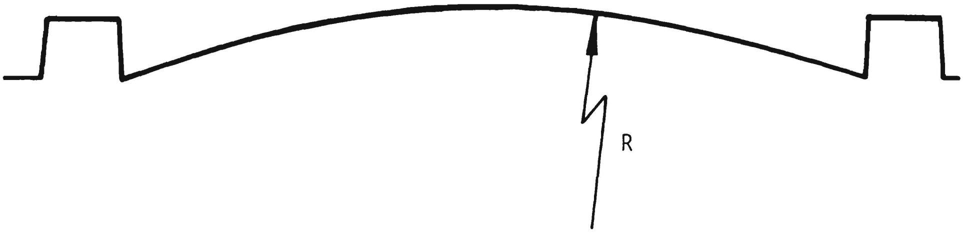


FIGURE 2a FIGURE 2b FIGURE 2c

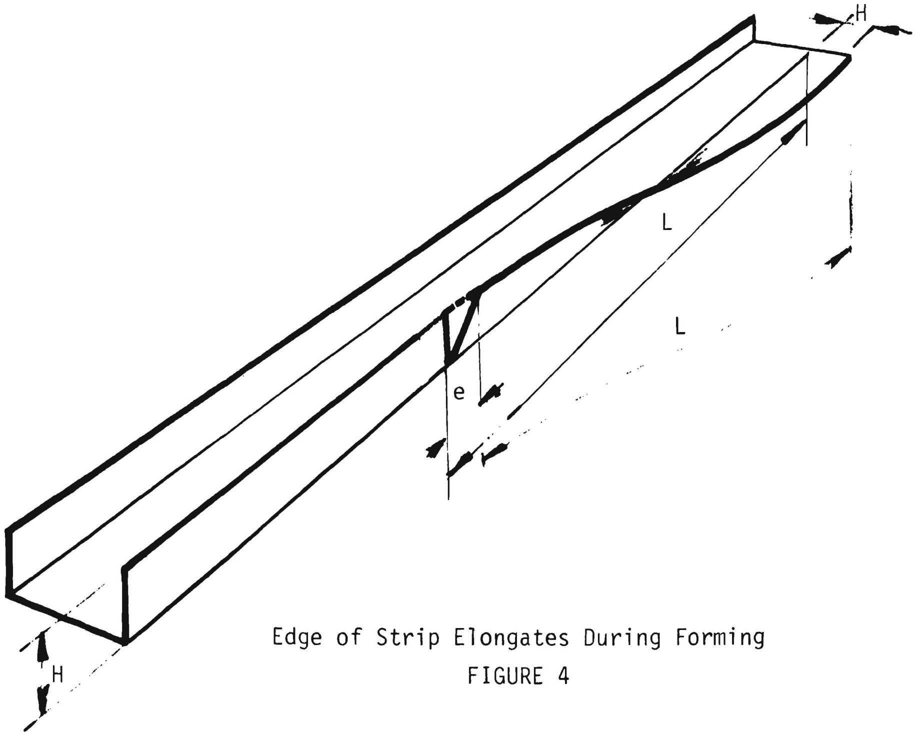
Effect of Top Roll Adjustment on Formed Shape

FIGURE 2



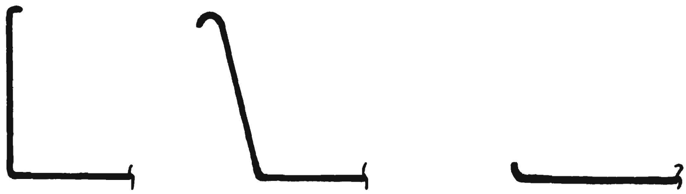
It is Difficult to Maintain Shape with Large Radius/Thickness Ratio

FIGURE 3



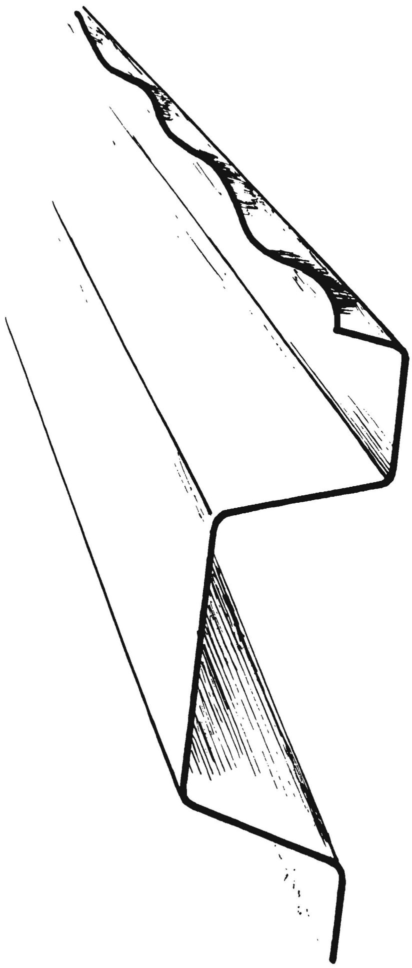
Edge of Strip Elongates During Forming

FIGURE 4



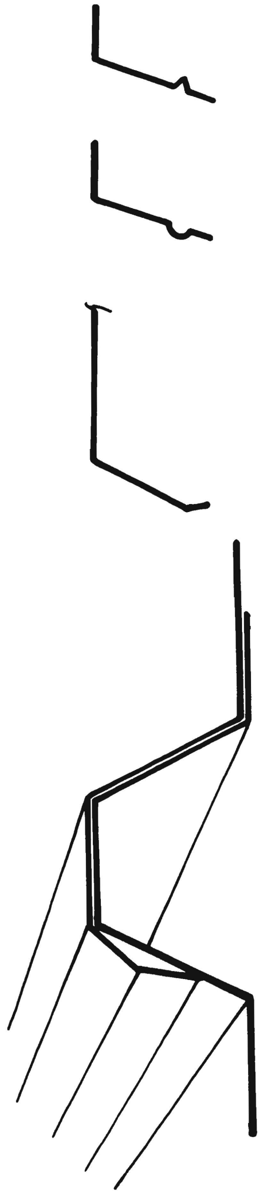
It is Tough to Form Short "Leg"

FIGURE 5



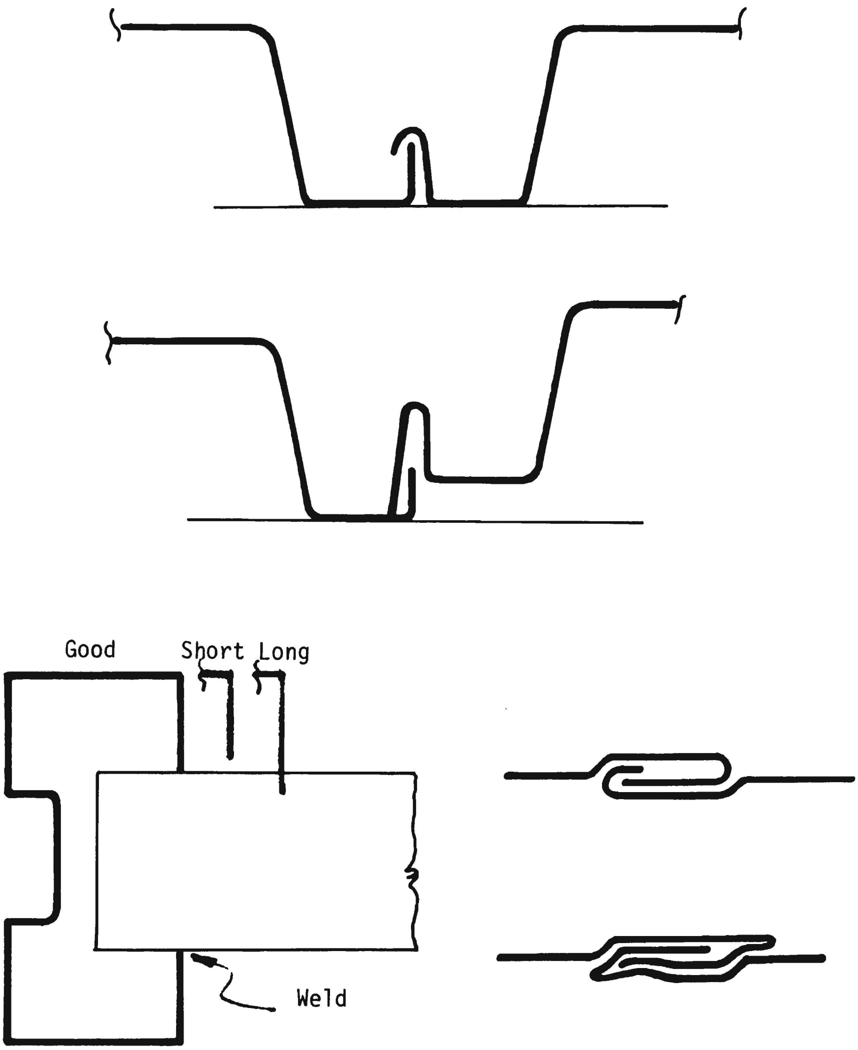
Wide Edge Bent Up or Down will be Frequently Wavy

FIGURE 6



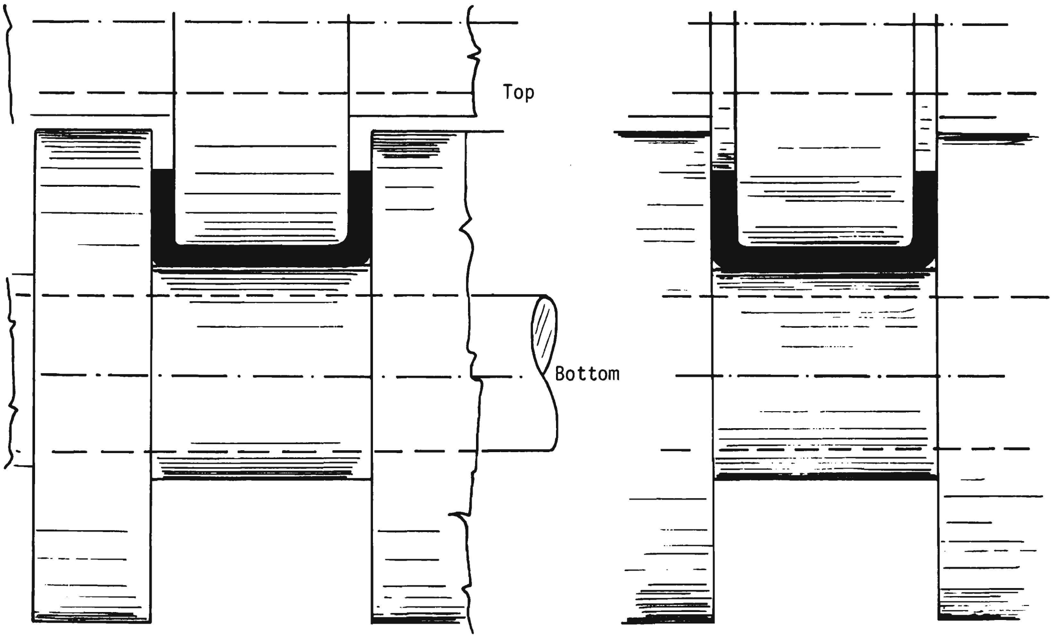
Waviness Can Be Avoided By Adding Bend Lines Close To The Edge

FIGURE 7



Too Short or Too Long "Legs" May Create Assembly or Erection Problems

FIGURE 8



Not Confined (Left) and Confined (Right) Rolling of "U" Channels

FIGURE 9

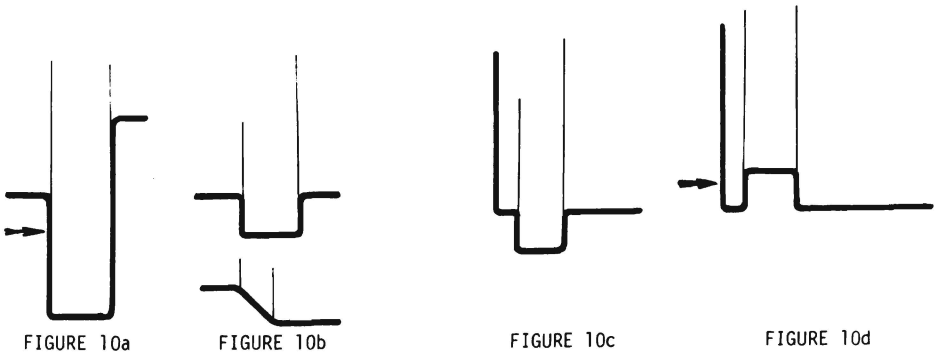


FIGURE 10a
Avoid
if Possible

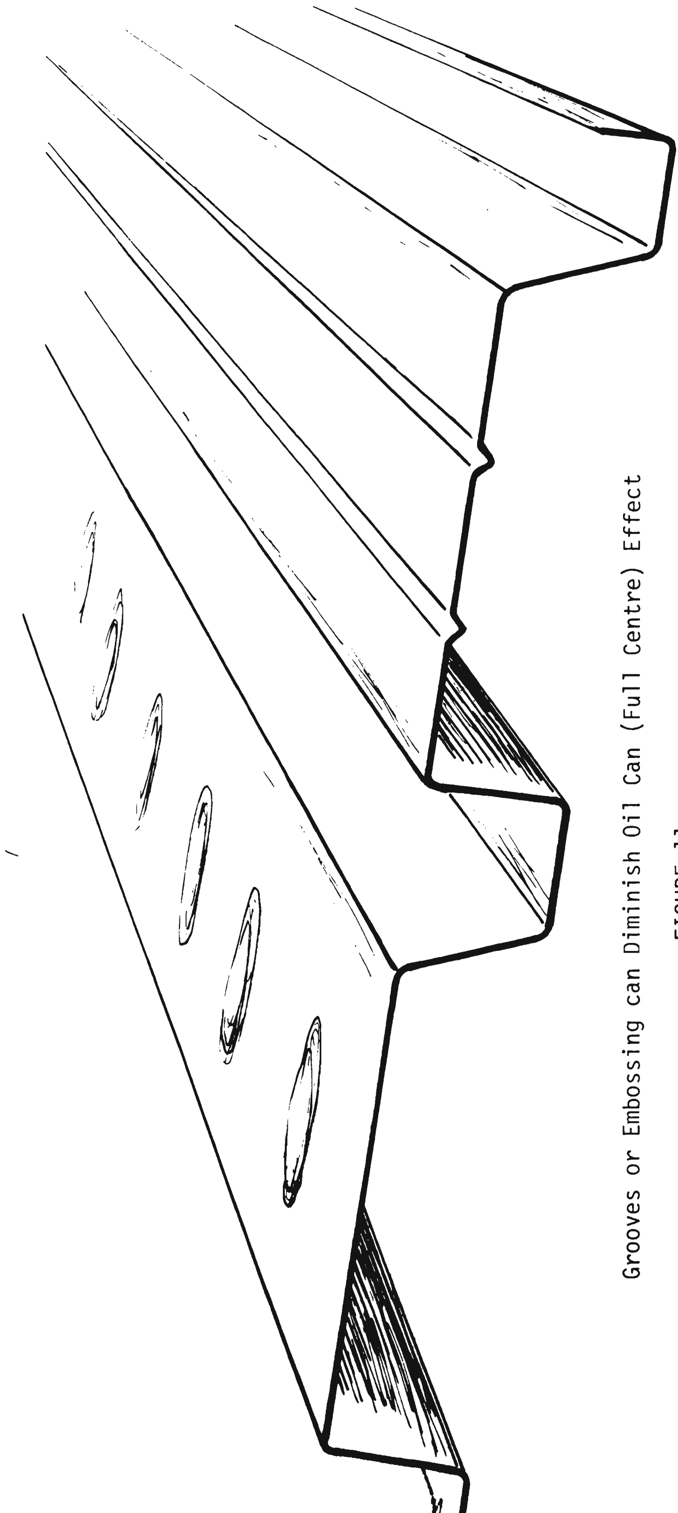
FIGURE 10b
Good

FIGURE 10c
Acceptable

FIGURE 10d
Not Recommended

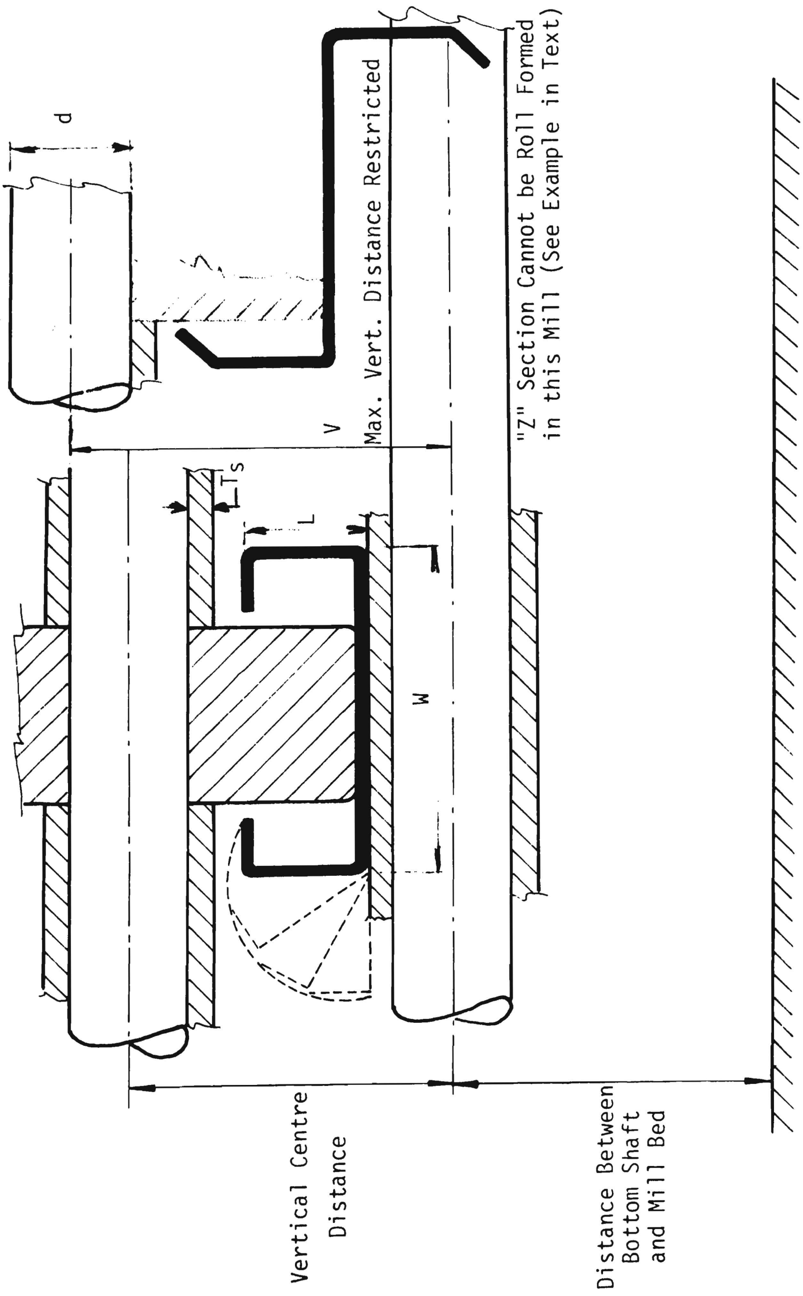
Arrows Indicate Where Relatively Thin Rolls May Break

FIGURE 10



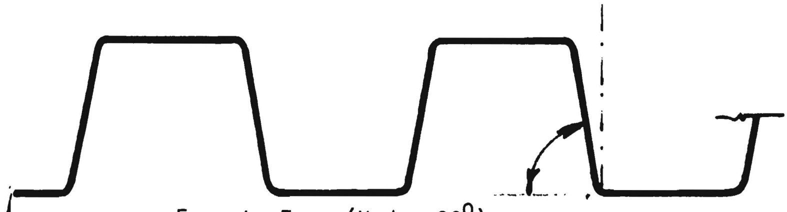
Grooves or Embossing can Diminish Oil Can (Full Centre) Effect

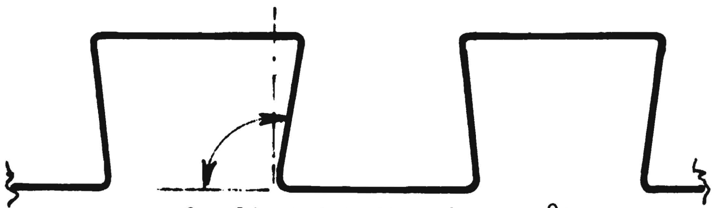
FIGURE 11



The Maximum Vertical Centre Distance Between Shafts May
Restrict The Height of Sections to be Roll Formed

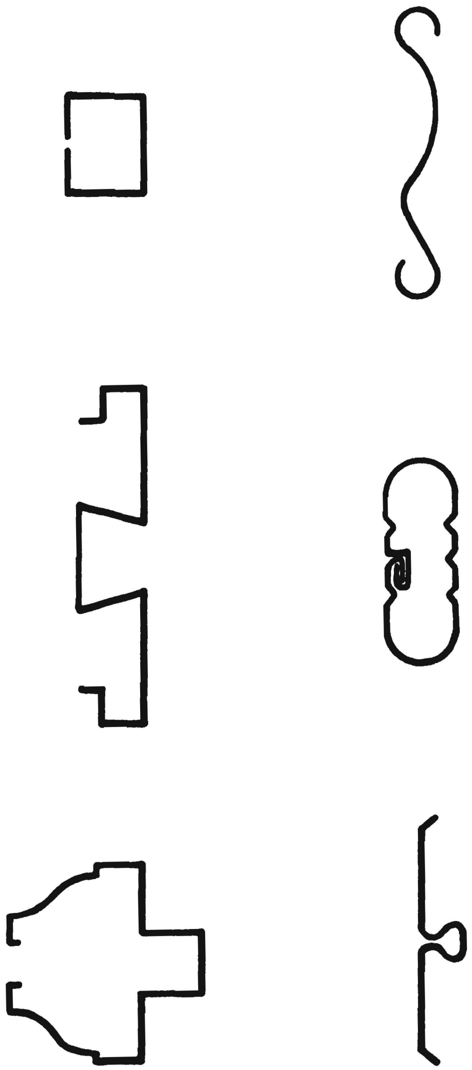
FIGURE 12





Effect of Forming Angles on Rolling Wide Panels

FIGURE 13



Complicated Shapes With Variety Of Angles And Radii Can Be Roll Formed

FIGURE 14

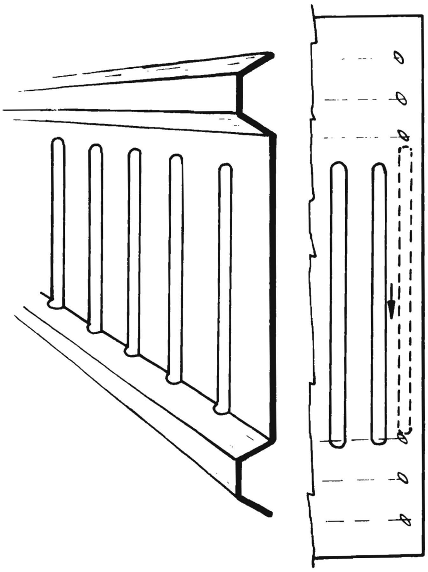


Figure 15b

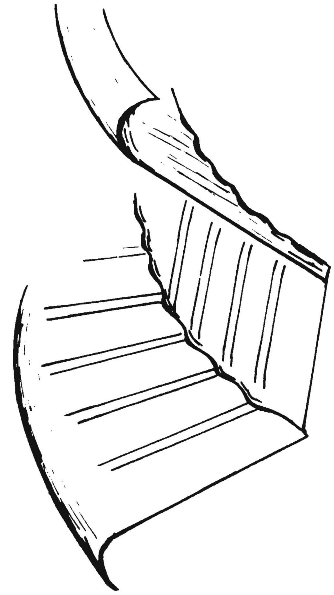


Figure 15d

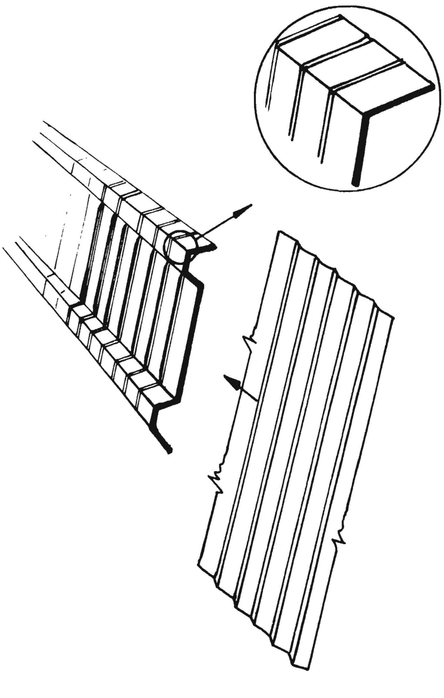


Figure 15a

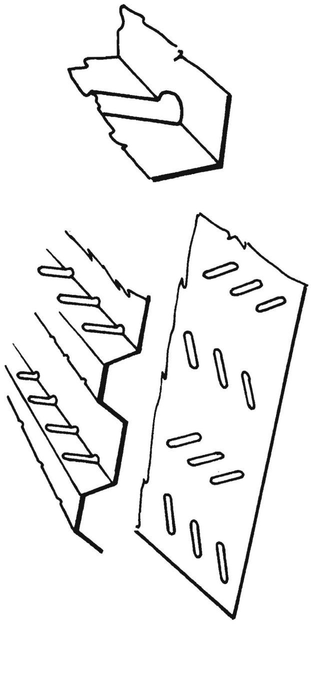


Figure 15c

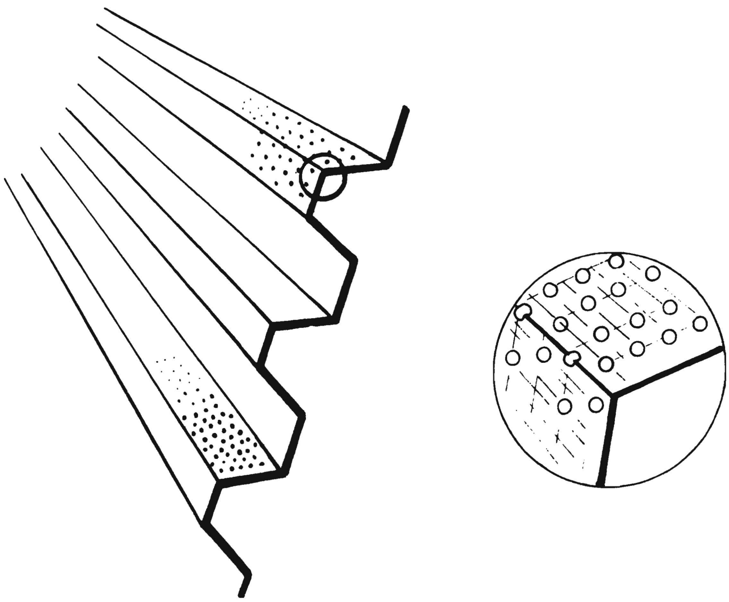


Figure 15f

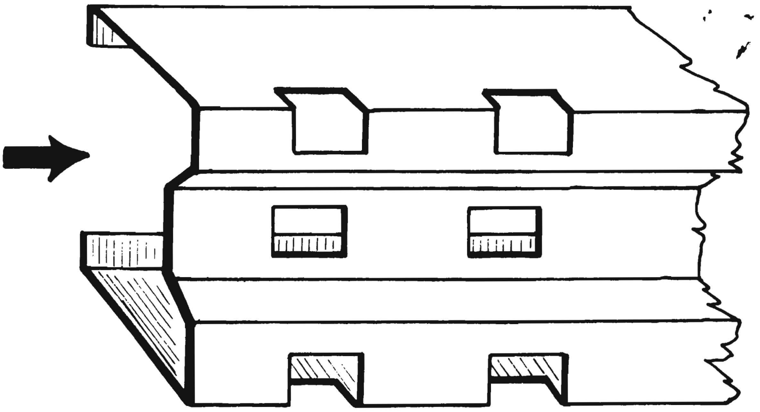
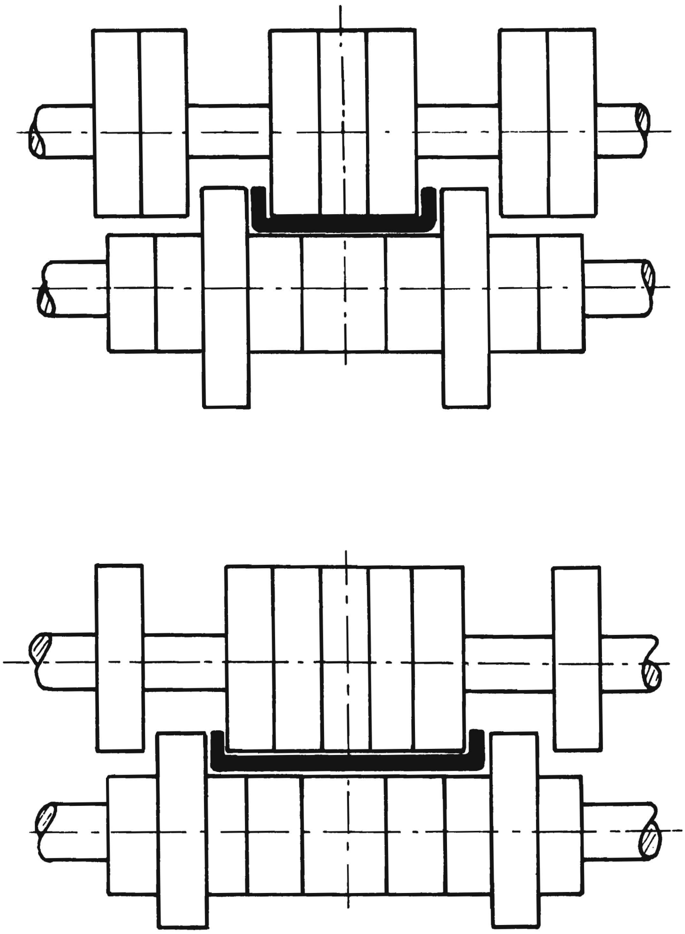


Figure 15g

Discontinuity in Formed Edge Reduces Strength
FIGURE 15



Width of "U" Channel can be Changed by Exchanging Rolls on the Shaft

FIGURE 16

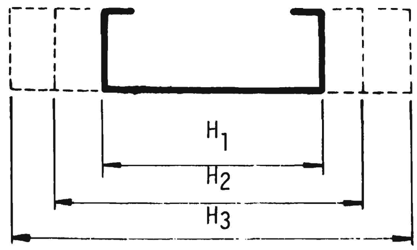


Fig 17a

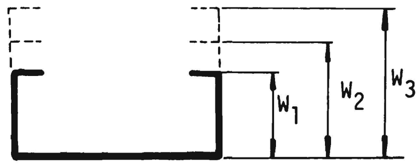


Fig 17c

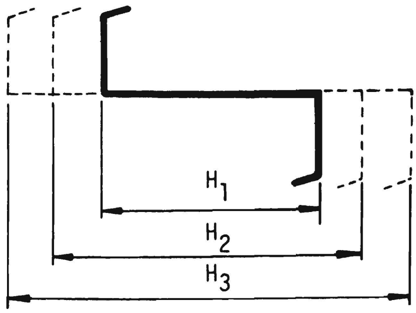


Fig 17b

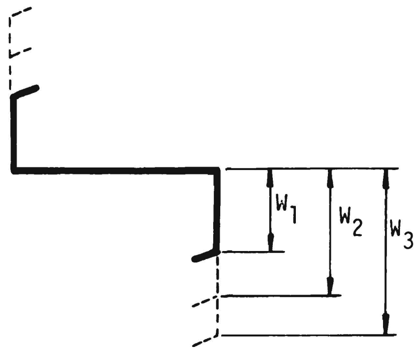


Fig 17d

One Set of Rolls can be Used to Manufacture Sections with Variable "H" (Fig 17a and 17c) but Separate Set of Rolls are Required for each Different "W" sizes (Fig 17b and 17d)

FIGURE 17

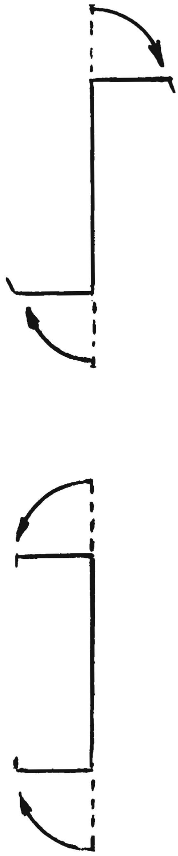


Fig 18a

Fig 18b

Symmetric and Asymetric Forming

FIGURE 18

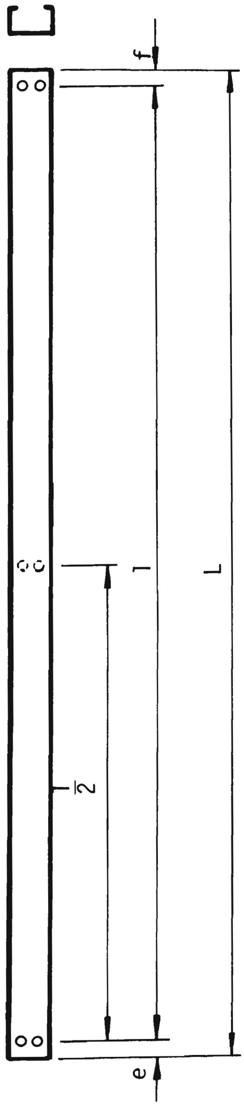


FIGURE 19